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**See Annex of J. Pamela et al., "Overview of Recent JET Results and Future Perspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

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ABSTRACT.

Large current densities can be present at the plasma edge in ELMy H-modes, from ohmic, bootstrap, Pfirsch-Schlüter and diamagnetic components, in toroidal and poloidal directions.

If during an ELM the edge flux surfaces of the plasma peel-off, there would be a sudden reduction in plasma toroidal current, amongst other quantities. The externally controlled poloidal field coils can not react in the time-scale of the ELM event, and in consequence the X-point and strike points would jump upwards (in the case of a lower X-point), in a fast time scale, such as the time for direct flow of particles along open field lines.

Peeling is fundamentally different from the change in equilibrium that would be derived simply from a reduction in poloidal b, in the usual "transport model" of the ELM. In that model, the flux surfaces are assumed unaltered, but transport coefficients are increased suddenly at the plasma edge. The strike points would then move in the transport time scale. Special experiments were designed to test this hypothesis: large, infrequent ELMs provide the best target plasmas, minimizing temporal and spatial resolution diagnostic problems.

1. EXPERIMENTAL OBSERVATIONS OF STRIKE POINT MOVEMENTS

Streak pictures from the Infrared Camera (IR), viewing the strike region, show a sudden upward jump in power deposition. Temperature contours as a function of Z and time are shown in Figs.1 and 2. The frame time is 3ms, the line time is 65µs. As shown in the figures, there is clear evidence that the strike jump can be as fast as 65µs (or faster).

Langmuir Probes (LP), operating in ion saturation mode, provide another measurement of strike point position, as the location of the maximum ion saturation current. The observed jumps are of the same approximate magnitude as the IR data indicates, as shown in Fig.3. A subsequent quick jump down of the inner strike is also observed by LPs, although not always detected by the IR system. We know of no explanation for this rapid downward shift, often observed. In Fig.3 we also plot the IR measured height of the hottest spot, a good indicator of inner strike position, due to the fast thermal response of a thin deposited layer. In the outer divertor the data was shifted upwards 3.5cm to match the LP measurement (a likely camera misalignment). As the thermal response is slower (no deposited layers) the position of maximum temperature plotted in Fig.3 does not jump, even if the corresponding heat deposition has a fast jump, as was shown in Fig.2.

2. GLOBAL PLASMA MOVEMENT?

A simple explanation to the above observations would be that the plasma centre may have suddenly moved inward and upward. We describe here the evidence against this possibility.

The position of the centre of SXR emission shows a sudden (<0.1ms) downshift of 7mm (not understood), shown in Fig.4, followed by a return to the previous position in <0.1ms, and a slow upward and then downward drift. The fast down-shift of the centre coincides with the upward shift of the strikes (LPs), so it is unlikely that one explains the other. The slow drifts are driven by the position control system, confused by measurements of the current centroid, which fail in fast time-scales. In the slow, 2ms time-scale, magnetic and SXR measurements of central position agree (not shown), as do IR and LP for the strikes.

The plasma density is measured with a Li beam at the plasma top (100ms time resolution), along a vertical line, and as a line integral in 3 vertical lines at either side of the centre, and at the outer edge (up to 1ms resolution). After each ELM, erosion of the plasma top is observed, as shown in Fig.5(a). Since the plasma centre has not moved down, the erosion is due to a loss of density from the top edge surfaces. The sudden drop in all line integrals of density, shown in Fig.5(c), indicates fast loss of particles, not an in-out movement.

3. MODELLING PLASMA PEELING

Using Motional Stark Effect and Polarimetry (MSE+P) measurements, the plasma equilibrium has been reconstructed, albeit with large error bars, induced by large radial electric fields (not measured), high density at the plasma core and low time-resolution, of order 20ms. The reconstructed current density profile before the ELM is shown in Fig.6. As is well known, equilibrium reconstruction is an art: this current profile is indicative only. It is sensible, physically, since $J_{tor} = Rp' + FF'/R$, and $p'<0$, $FF'>0$ are typically associated with diamagnetic regions in plasma, with large pressure gradients.

A linearized plasma response model of the plasma equilibrium [1] is used to compute a new equilibrium by peeling surfaces outside $\Psi = 0.95$ ($\Psi = 1$ at LCFS), taking into account induced currents in passive structures (large in sudden events in JET). The final current density profile is also shown in Fig.5. The peeling results in loss of 90kA of toroidal current, a drop in β from 0.78 to 0.64, and upward strike jumps of 7cm inboard, 5cm outboard, in qualitative agreement with experimental observations. The plasma boundary jumps upwards and inwards, in agreement with previous observations [2]. Notably, reconstruction of some discharges without MSE+P can give good quantitative agreement of measured strike jumps with the peeling model. The sensitivity of the peeling results to initial equilibrium profiles is under investigation. Equally, a simulation of a pure β drop will be attempted in the future, as it requires information about profile evolution.

4. IMPLICATIONS FOR ITER

If ELMs correspond to plasma peeling, and lead to current loss and strike jumps, as we appear to observe in JET, then the same phenomenon would be expected in ITER. As the ITER edge is expected to be very hot, edge resistivity can be lower than in JET, and therefore edge current can be proportionally larger. This leads us to believe that strike jumps are expected in ITER, although it is not possible yet to predit their magnitude (proportionality with I_p?). They may in fact be beneficial, as heat would be deposited in a previously cooler material surface, and erosion could be reduced. On the other hand, very fast heat deposition (<65ms) may be worrying. Equally, if peeling is the explanation for the ELM, it may not be localised to the divertor area, as the open field lines could transiently lead to other points inside the vessel.

CONCLUSIONS.

At an ELM, the plasma strike points are clearly observed to jump upwards, in 100ms or less, in a large variety of situations. Fast loss along open field lines, which were previously closed flux surfaces, is the simplest explanation for the combined observations of strike jumps. Modelling indicates that an upward jump of the strike points can be associated with plasma toroidal current loss, of order 50-100 kA, and not simply a shift of the plasma centre.

ACKNOWLEDGEMENT

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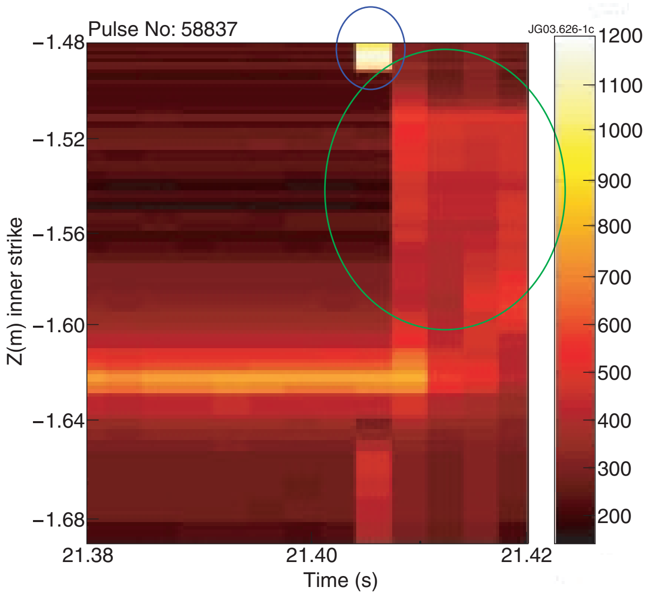

Figure 1: Inner strike jump, IR measurement.

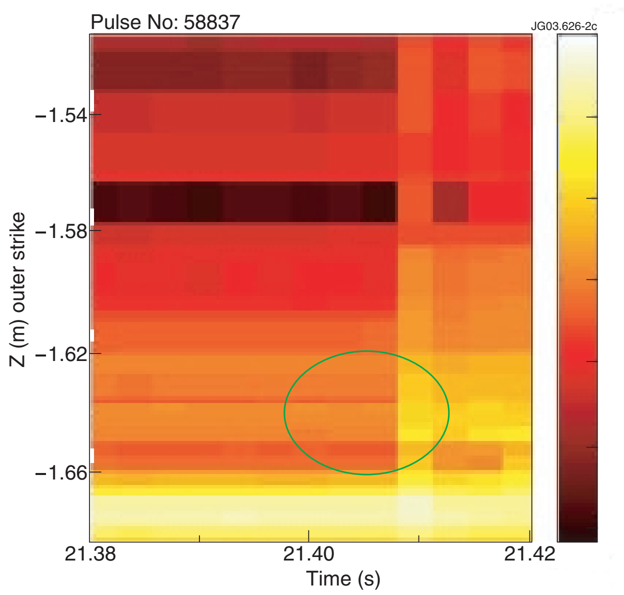

Figure 2: Outer strike jump, IR measurement.

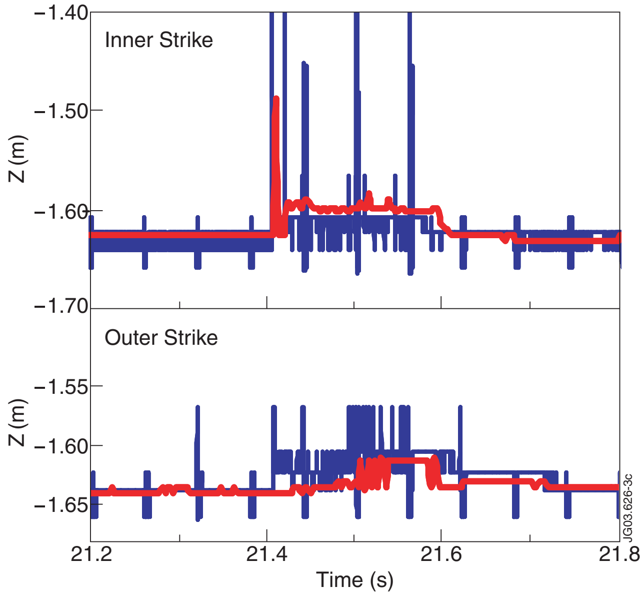

Figure 3: Strike jumps, inner and outer, measured with Langmuir Probes (blue) and position of maximum IR-measured temperature (red). Note: periodic (60ms) vertical jumps in LP meas. are an artefact to be ignored. JET Pulse No: 58837

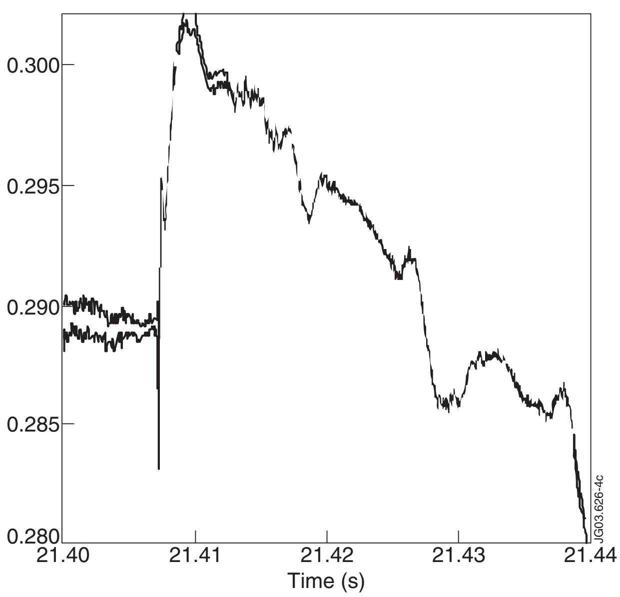

Figure 4: Vertical position of SXR centroid.

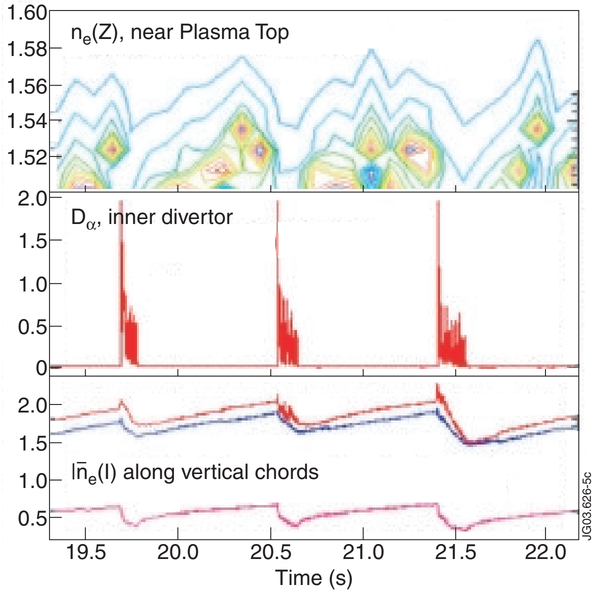

Figure 5: (a) Density profile (Li beam) (b): D_α in inner divertor. (c): $l\ \bar{n}_e$ along central inner (red), outer (blue) and edge (pink) vertical lines.

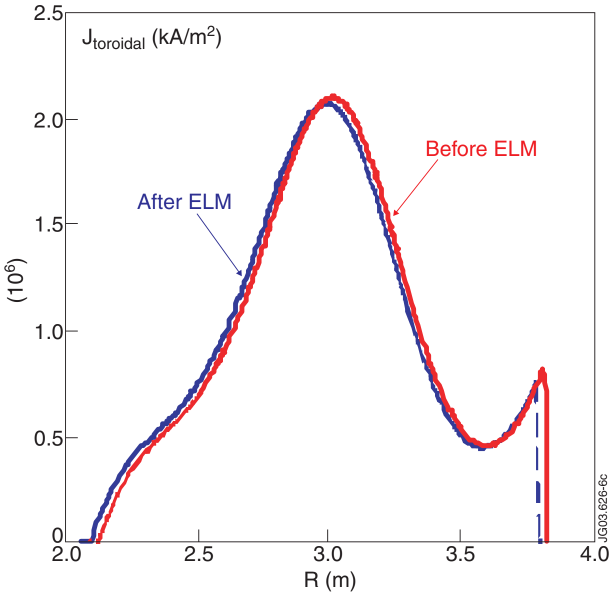

Figure 6: Toroidal current density as a function of major radius at axis height, (red) before ELM, (blue) after ELM